

Diversity reception controller helps radio system performance

Part 1—Short-term (multipath) fading can fluctuate received signals as much as 50dB. Without an adequate fade margin or other solutions, high-speed data communications can be adversely affected or entirely ruined.

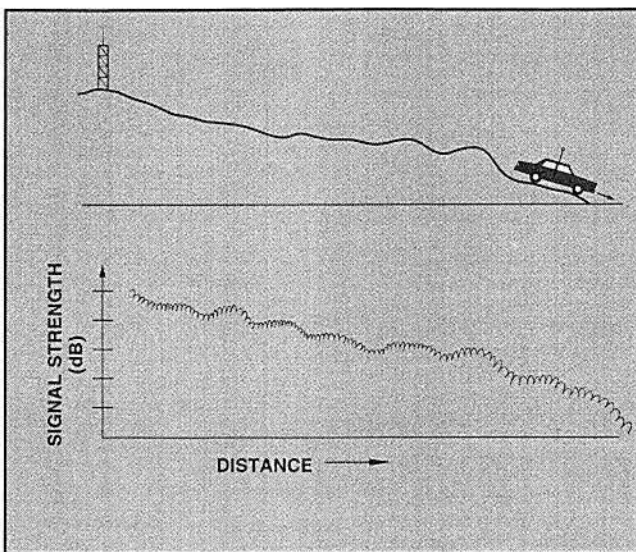


Figure 1. Long-term fading is caused primarily by distance and terrain. In general, as the distance between transmitter and receiver increases, the signal amplitude tends to decrease. Received signal levels tend to be stronger when the mobile receiver is on hilltops with a line-of-sight radio path to the transmitter. Signals are weaker when the line-of-sight path is blocked by terrain.

By Shane Fitzgerald

The best criterion for evaluating radio system performance is the mobile user's ability to communicate successfully, defined as meeting or exceeding a standard of performance.

A radio receiver's ability to meet a performance standard is a function of the received signal strength. If the received signal is at or greater than the level required, successful communication is possible. If the received signal is less than the re-

Fitzgerald is RF design engineer at ElectroCom Communications Systems, Santa Fe Springs, CA. ElectroCom manufactures the ideal selection diversity controller described in this two-part article.

quired level, successful communication is not possible.

Short of equipment failure, there is only one reason for the received signal amplitude to fall below the required level: *fading*. Fading is unquestionably the greatest cause of failed mobile radio communications. Reducing the effects of fading leads to significant improvements in radio system performance.

Two types of fading are present in the mobile radio environment, long-term fading and short-term fading.

Long-term fading is caused primarily by distance and terrain. In general, as the distance between transmitter and receiver increases, the signal amplitude tends to decrease. Received signal levels tend to be stronger when the mobile receiver is on hilltops with a line-of-sight radio path

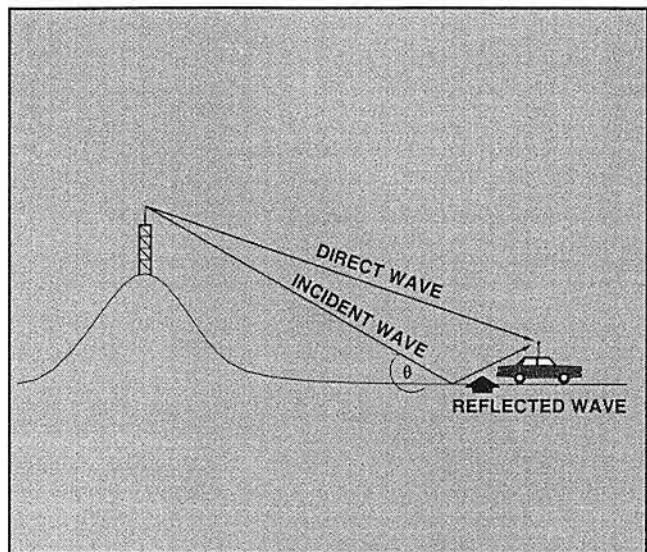


Figure 2. Short-term (multipath) fading is caused by a physical characteristic of electromagnetic waves. A direct wave travels from the transmit antenna to the mobile receiver antenna. In addition, an incident wave strikes the ground close to the vehicle and reflects upward and into the receiver antenna.

to the transmitter. Signals are weaker when the line-of-sight path is blocked by terrain. (See Figure 1 above left.)

Long-term fading has a gradual effect. As a receiver moves through a radio system's coverage area, the signal amplitude gradually moves up and down in response to distance and topography. The effects of long-term fading cannot be corrected at the mobile unit. Coverage deficiencies induced by long-term fading can be corrected only by changing the number or location of the radio sites, or by using on-frequency-repeater technology.

Short-term (multipath) fading is caused by a physical characteristic of electromagnetic waves. (See Figure 2 above right.) A direct wave travels from the transmit antenna to the mobile receiver antenna. In addition, an incident wave

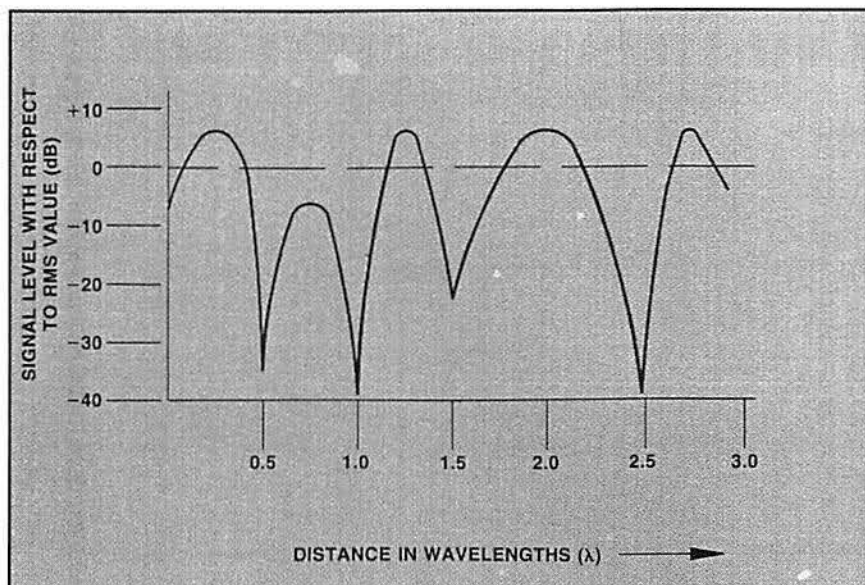


Figure 3. When a mobile receiver moves through an area, large fluctuations in received RF amplitude result. These fluctuations are periodic and occur at half-wavelength intervals (6.9 inches at 850MHz). The dynamic range of these fluctuations is about 50dB.

strikes the ground close to the vehicle and reflects upward and into the receiver antenna. The power in the reflected wave

depends on the angle of incidence (θ) and the ground's reflection coefficient. For average soil, the reflected wave's magni-

tude exceeds 0.9 when θ is less than 10° (which almost always is the case in land mobile communications). This small difference in magnitude means that the reflected wave's amplitude will be similar to the direct wave's amplitude. The mobile receiver responds to two sources of radio energy, the direct wave from a distance and the reflected wave from the ground in close proximity to the receiver.

When an electromagnetic wave strikes a reflector, its phase shifts 180° , a phenomenon known as specular or mirror-image reflection. These two waves, direct and reflected, interact to form a standing wave pattern of *constructive* and *destructive* interference.

Because it is impossible to see an electromagnetic standing wave pattern of constructive and destructive interference, it might be difficult to visualize. The water waves in a ripple tank demonstrate the phenomenon. (See Photo 1 on page 56).

In the ripple tank, two small floating balls (located at the center of the two circular patterns) are attached with strings to vertical oscillators on the bottom of the tank. As each ball oscillates up and down, it creates waves. Waves from the two

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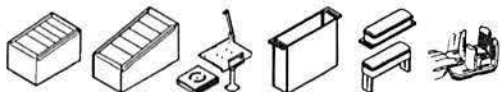
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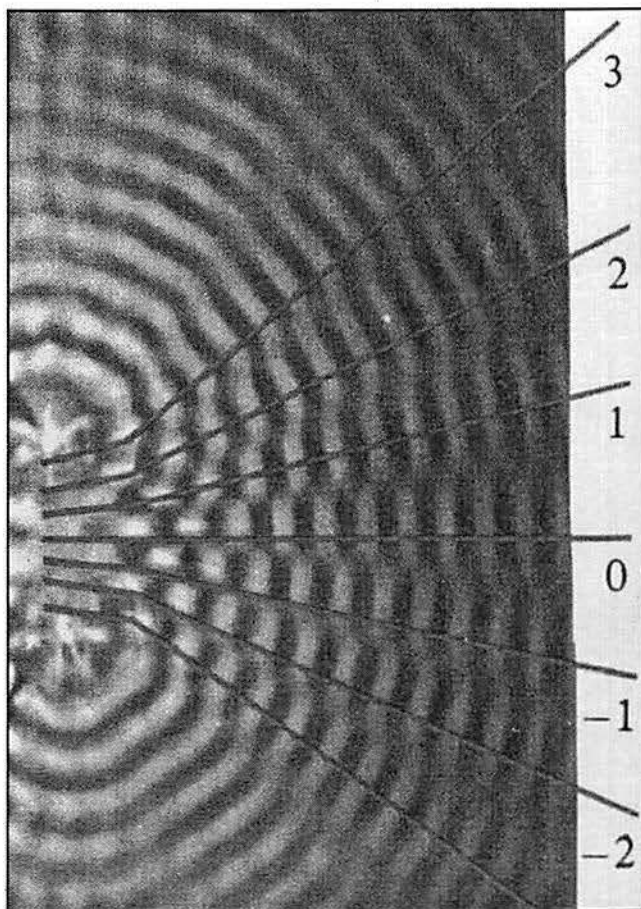


Photo 1. Because it is impossible to see an electromagnetic standing wave pattern of constructive and destructive interference, it might be difficult to visualize. The water waves in a ripple tank demonstrate the phenomenon.

sources react with each other to form the standing wave pattern visible in Photo 1.

This two-source interference pattern re-

sembles the direct and reflected radio-frequency (RF) standing-wave pattern created by two sources of radio energy. Clearly

visible in the photo are the lighter shades of the crests and the darker shades of the troughs of the standing-wave pattern.

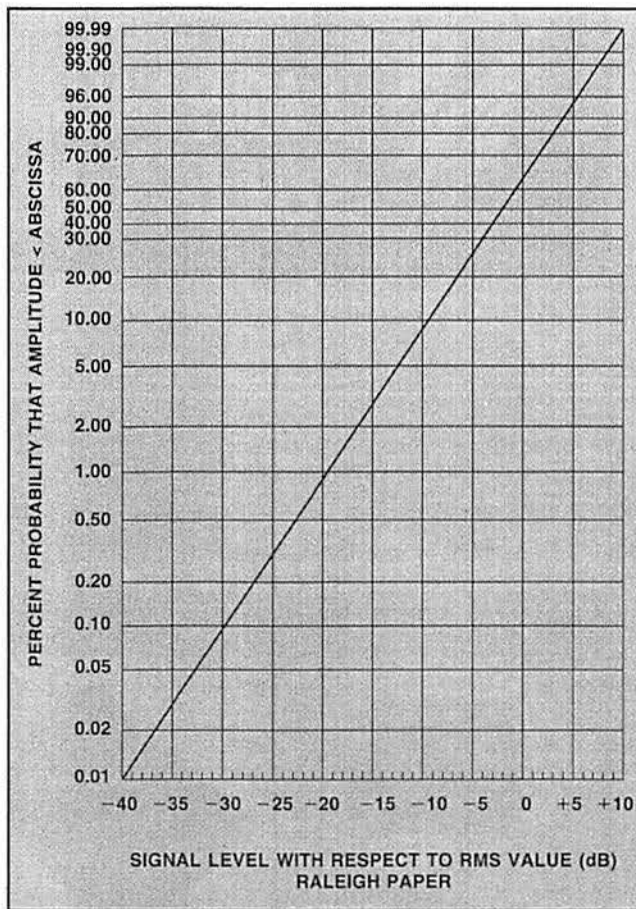


Figure 4. Signal amplitude at any given point ranges from 10dB above the average value to 40dB below the average value. This distribution is presented in its most useful form—Rayleigh paper.

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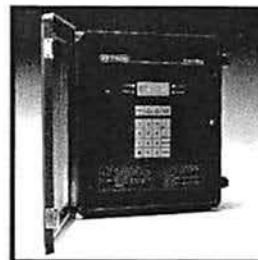
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The distance from maximum to minimum amplitude of the standing-wave pattern is one-half wavelength of the frequency of oscillation of the floating balls. Similarly, the distance from crest to crest or from trough to trough of short-term mobile radio fading is one-half wavelength of the radio waves' oscillation.

When a mobile receiver moves through an area, large fluctuations in received RF amplitude result. These fluctuations are periodic and occur at half-wavelength intervals (6.9 inches at 850MHz). The dynamic range of these fluctuations is about 50dB. Figure 3 on page 54 illustrates amplitude variations that a moving vehicle typically might encounter.

The distribution of short-term fading is a function of two random variables and is the sum of coherent sinusoidal waves of random phase and random amplitude. This sum describes exactly the mobile radio short-term fading phenomenon, which sometimes is referred to as *Rayleigh fading* after Lord John William Strutt Rayleigh (1842-1919), a British physicist who first described the distribution.

Signal amplitude at any given point ranges from 10dB above the average value to 40dB below the average value. This

distribution is presented in its most useful form—Rayleigh paper—in Figure 4 on page 56.

Rayleigh paper is an extremely useful tool for determining the percentage of probability that a signal will be above or below the average value. Numbers across the bottom of the graph represent signal amplitude (with respect to the average value) in decibels; therefore, 0 is the average value.


To find the percentage of probability of encountering a fade 20dB less than the average, follow the vertical -20dB line upward until it intersects with the diagonal line. Then read the graph directly to the left. In this example, there is a 1.0% probability of encountering a fade of 20dB.

Fade margin is an RF system design characteristic that indicates the system's ability to tolerate fades. It is expressed in decibels above the threshold where reliable communication takes place. As long as the average RF signal amplitude is 40dB above the level necessary for reliable communications—a figure that represents a 40dB *fade margin*—short-term fading will have no noticeable effect on the ability to communicate. Unfortunately, maintaining a 40dB fade margin in the field is practically impossible.

When a given geographic area's fade margin is 20dB, 1% of the locations within the area will have RF amplitude below what is required for communication. If the fade margin is 10dB, then 10% of the locations will have RF amplitudes below that required for communications.

For voice communication via radio, fade margin can be translated directly into system reliability because short-term fading effects on voice communication are more of a nuisance than a serious problem. The mind's processing power enables a listener to understand a voice message despite occasional noisy pops and hisses.

Short-term fading is extremely destructive to high-speed data communications. What the ear would endure as one little pop or a hissing sound may destroy several hundred bits of information. A mobile unit traveling at 15mph through a stationary environment will encounter 38 fades per second, and more if the environment includes moving objects such as trains, aircraft and automobiles. If these fades sink below the receiver's data recovery threshold, successful data reception becomes nearly impossible.

Next: How the integrity of data communications can be protected in a fading environment. 

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Diversity reception controller helps radio system performance

Part 2—Using amplitude sensing, analog logic and output filtering along with low-cost integrated circuitry, an ideal selection diversity controller brings the advantages of diversity reception to commercial mobile communications.

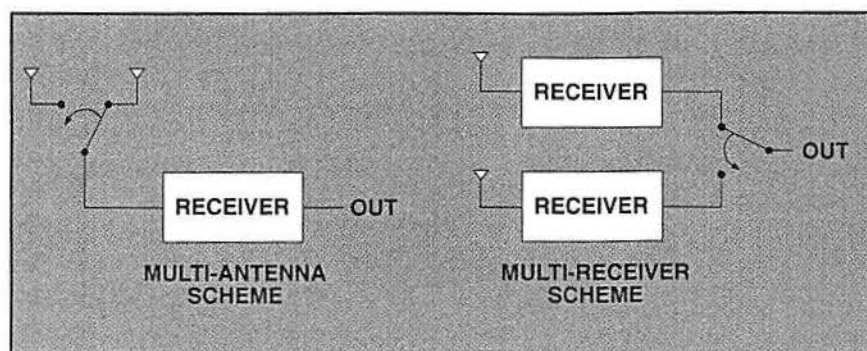


Figure 1. There are literally hundreds of variations on the concept of diversity reception. Most can be grouped into two main classifications of diversity reception systems, *multi-antenna systems* and *multi-receiver systems*, as shown above. Both of these schemes have proven largely unsuccessful, both technically and commercially, for a number of reasons.

By Shane Fitzgerald

Short-term (multipath) fading, as described in the first installment of this two-part article, is extremely destructive to high-speed data communications. What the ear would endure as one little pop or a hissing sound may destroy several hundred bits of information. An 800MHz mobile unit traveling at 15mph through a stationary environment will encounter 38 fades per second, and more if the environment includes moving objects such as trains, aircraft and automobiles. If these fades sink below the receiver's data recovery threshold, successful data reception becomes nearly impossible.

How can the integrity of data communications be protected in a fading environment? Two of the most popular and widely used methods are *forward error-correction*

(FEC) and redundant transmissions.

With FEC, message reconstruction information is attached to each message prior to transmission. Should the message be received with errors, the reconstruction information is used to reconstruct the message. This method is complex. Message reconstruction taxes the receiver's processing power because it is computationally intensive, and it reduces system throughput significantly because an FEC code is added to each transmission.

With redundant transmissions, each message is transmitted multiple times and a majority voting process is used to decode the message. This simple scheme is less computationally intensive than FEC; but multiple transmissions of identical information are extremely inefficient and dramatically reduce system throughput.

FEC and redundant transmissions share two fundamental flaws in dealing with the destructive interference caused by multipath fading. The first flaw these systems exhibit is their fatalistic approach to the problem. Instead of trying to eliminate the source of the problem (short-term fading), these techniques try to recover from

the damage the fading causes. The other flaw is that if the receiver remains stationary while in a deep fade, no amount of FEC or redundant transmissions will help; communication will not be possible.

Diversity reception, on the other hand, reduces destructive effects of multipath fading directly. Two closely spaced antennas receive signals that are considered to be uncorrelated; therefore, when one antenna experiences a fade, then the probability of the other antenna simultaneously experiencing a fade is extremely unlikely. By selecting between antennas or receivers quickly enough and in response to the fades, the damaging effects of short-term fading are dramatically reduced.

There are literally hundreds of variations on the concept of diversity reception. Most can be grouped into two main classifications of diversity reception systems, *multi-antenna systems* and *multi-receiver systems*, as shown in Figure 1 at the left. Both of these schemes have proven largely unsuccessful, both technically and commercially, for a number of reasons.

Multi-antenna diversity uses a single receiver with multiple antennas that are connected to it one at a time. When the receiver picks up an adequate signal from its current antenna, it maintains the connection. If the signal falls below a predetermined threshold, then the receiver switches to another antenna that may deliver a better signal.

Unfortunately, there is no guarantee that a better signal will be found when the receiver switches antennas. The signal may, in fact, be worse. Moreover, waiting until the threshold of reliable communication is reached before switching means that a problem already has been encountered, rather than avoided.

Multi-receiver diversity uses multiple receivers to supply recovered modulation. Special circuitry determines which

Fitzgerald is RF design engineer at ElectroCom Communications Systems, Santa Fe Springs, CA. ElectroCom manufactures the ideal selection diversity controller described in this two-part article.

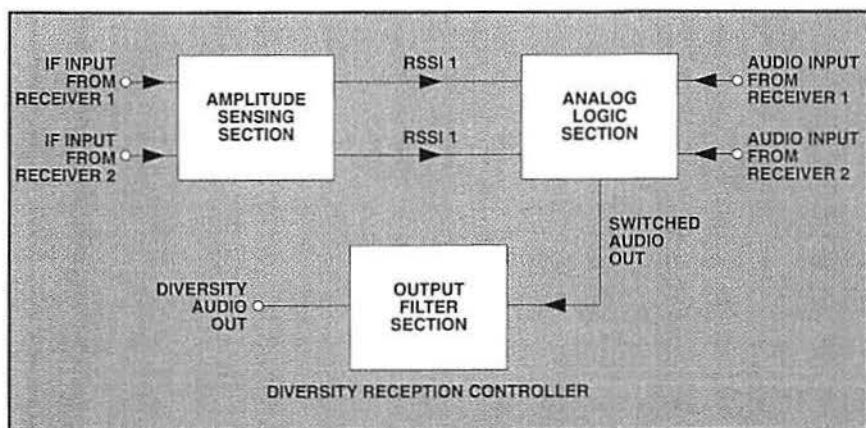


Figure 2. The diversity reception controller includes three main sections: an amplitude-sensing section, an analog logic section, and an output filter section.

receiver is receiving the better signal, and that receiver is then selected. Composite recovered modulation is assembled using a combination, or selection, algorithm. This process is technically complex. It has been largely unsuccessful because RF signal-level quantification circuitry cannot react fast enough to RF amplitude changes, and in the selection algorithm, high-speed switching between discontinuous signals causes damaging transients.

Fortunately, advances in performance along with reductions in the cost of integrated circuitry have enabled the development of a low-cost, highly efficient diversity reception controller that overcomes previous multi-antenna and multi-receiver problems. The controller's *ideal selection diversity* uses multiple receiver outputs that are selected by comparing RF carrier amplitudes.

Figure 2 above is a block diagram of the

diversity reception controller, which includes three main sections: an amplitude-sensing section, an analog logic section, and an output filter section.

The amplitude-sensing section contains high-speed, integrated, intermediate-frequency (IF) processors that provide IF amplitude information proportional to the received signal at each antenna. The processors generate an ultra-fast dc voltage received signal strength indicator (RSSI) proportional to the log of received power in decibels over a wide dynamic range.

The analog logic section processes the IF amplitude voltage, receives recovered modulation from the receivers and continuously selects recovered modulation from the receiver with the higher relative received signal.

The output filter section removes transients caused by high-speed switching between two discontinuous signals while ensuring constant input-to-output delays and fast settling characteristics. The filter can be programmed to accommodate all common IF bandwidths and response characteristics.

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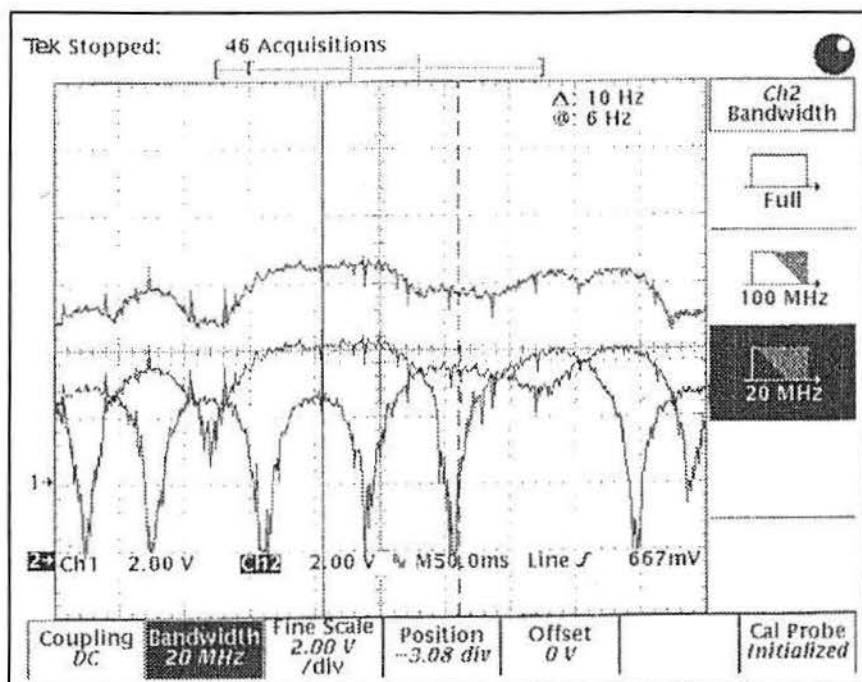


Photo 1. This digital storage oscilloscope display demonstrates the short-term fade reduction that an ideal selection diversity system provides during 500ms of reception in a vehicle traveling at 10mph. The lowest received signal strength encountered by the selected receivers was about -105dBm. Unselected receivers encountered numerous fades, six of which dipped to -130dBm.

Photo 1 at the left and Photo 2 on page 42 are plots taken from a digital storage oscilloscope connected to a diversity reception controller. These plots demonstrate short-term fade reduction that an ideal selection diversity system provides.

Ch1 (the upper trace) is the receivers' RSSI signal selected by the diversity reception controller to supply recovered modulation. Ch2 (the lower trace) displays the RSSI signals of the individual receivers. The diversity reception controller always selects the receiver with the higher relative signal level. This plot was taken in a vehicle traveling about 10mph. The plot is a 500ms snapshot of the short-term fading typically encountered in the mobile environment.

Voltages displayed on the oscilloscope plots correspond to the received signal amplitude as follows:

8.0V	-90dBm
6.0V	-100dBm
4.0V	-110dBm
2.0V	-120dBm
0.0V	-130dBm

As shown in Photo 1, the lowest received signal strength encountered by the selected receivers was about -105dBm.

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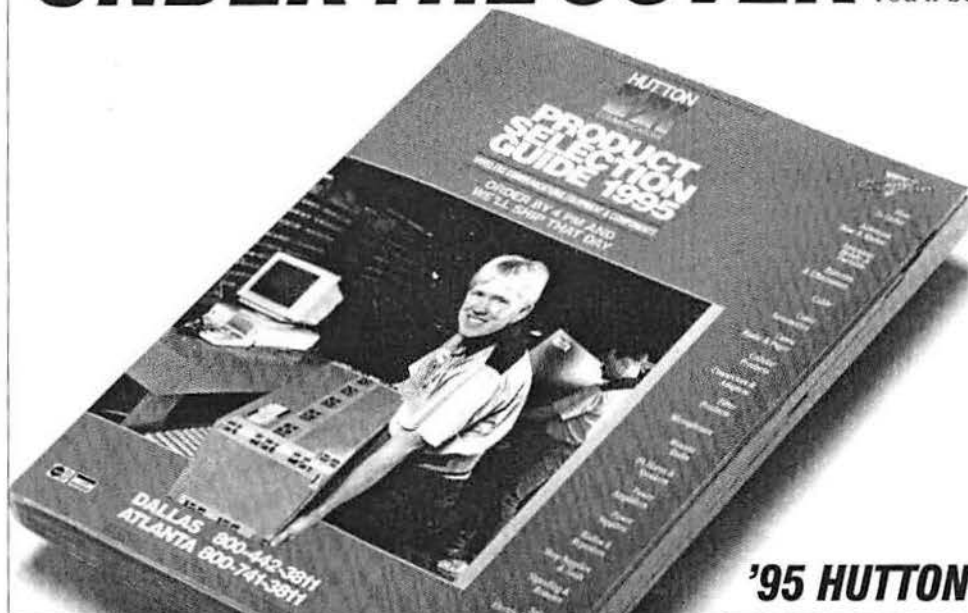
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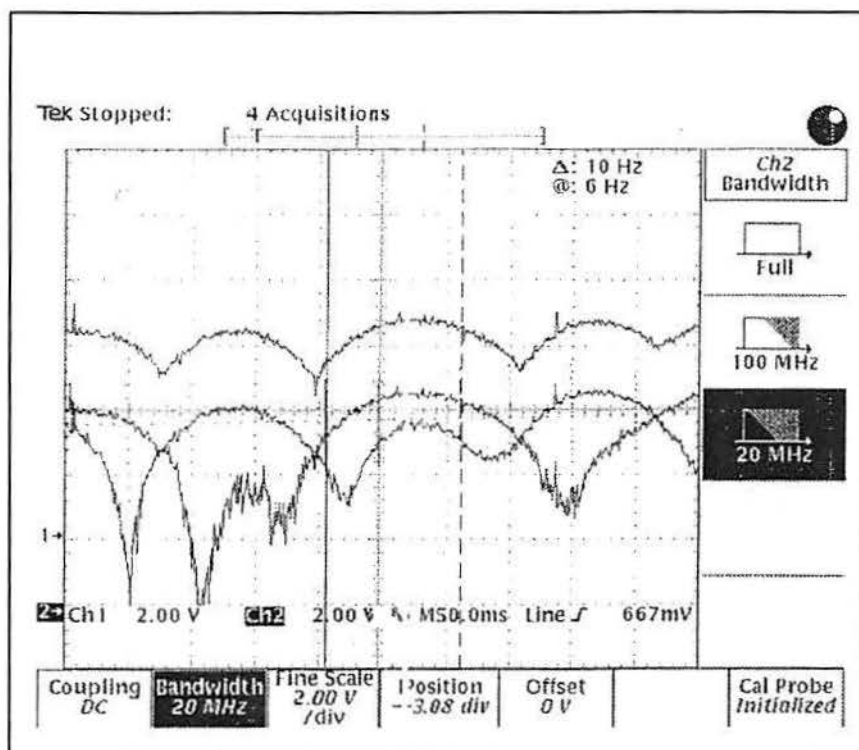


Photo 2. Another 500ms snapshot of typical short-term fading, taken at a slightly slower speed. Clearly evident is the classic shape of a Rayleigh distribution.

Unselected receivers encountered numerous fades, six of which dipped to -130dBm.

Photo 2 is another 500ms snapshot of typical short-term fading, taken at a slightly slower speed. Clearly evident is the classic shape of a Rayleigh distribution.

This diversity reception method's gain is proportional to the fade depth. For example, the percentage of probability of encountering a -10dB fade with ideal selection diversity reception is 1.0%, one-tenth of the percentage of probability without diversity. The percentage of probability of encountering a fade of -20dB with ideal selection diversity reception is 0.01%, one-hundredth of the percentage of probability without diversity.

Figure 3 on page 44 depicts this increase in fade protection. The left side of the graph indicates the percentage of probability of encountering a fade without diversity reception. The right side indicates the percentage of probability with a diversity reception controller.

The increase in performance provided by the diversity controller translates into system reliability. As seen in Figure 3, 99% reliability can be achieved with only a 10dB fade margin, representing a 10dB

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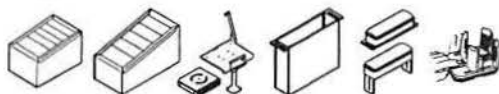
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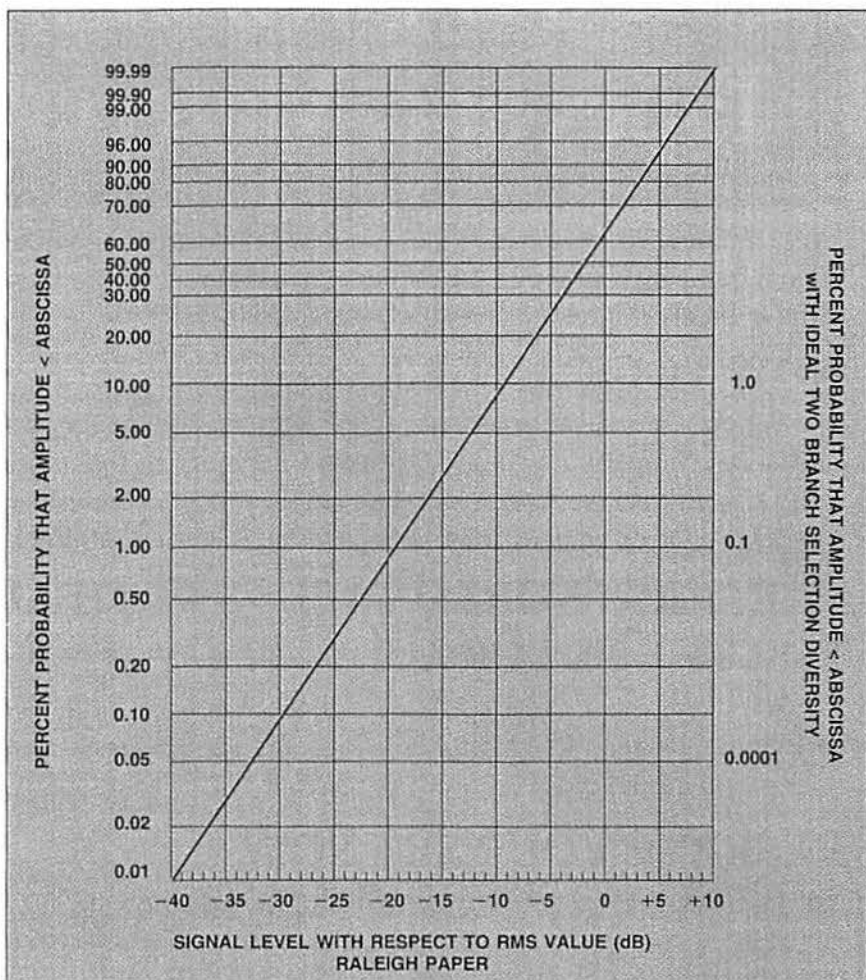


Figure 3. The increase in fade protection for ideal selection diversity reception is proportional to the depth of fades encountered. The left side of the graph indicates the percentage of probability of encountering a fade without diversity reception. The right side indicates the percentage of probability with a diversity reception controller.

improvement over a system without diversity reception. A 99.9% reliability can be achieved with a 20dB fade margin; this represents a 20dB improvement over a system without diversity reception.

Adding diversity reception to an existing radio communications system increases its coverage area and increases its reliability within any given area. For data communications systems, the success rate of first-attempt delivery of data messages rises dramatically, regardless of vehicle speed.

For voice communication, the diversity reception controller provides an 8dB-10dB improvement in signal-to-noise ratio (S/N).

The diversity reception controller can retrofit existing radio systems with the performance advantage of ideal selection diversity reception. An entire fleet can undergo retrofit, or only specific vehicles (such as vehicles that frequent poor coverage areas).

Although the focus of this article has been mainly on the mobile receiver, the

base receiver or repeater receiver is subject to the same short-term fading effects as the mobile unit. In terms of performance vs. cost, equipping the system base or repeater station with diversity reception yields the most performance per dollar because the advantages of diversity reception are shared by all users.

A dramatic increase in performance of mobile-to-mobile communications is possible when both repeater and mobile receivers are equipped with the diversity reception controller. The uplink's recovered audio experiences an 8dB-10dB increase in S/N performance. This better-quality audio is repeated on the downlink to a diversity-equipped mobile receiver with an 8dB-10dB increase in S/N performance. The aggregate S/N performance increase can be as high as 16dB to 20dB.

The controller is easy to install with few connections required and is compatible with all existing communications receivers.